Journal of Neuro-Oncology (2022) 159:33–42
https://doi.org/10.1007/s11060-022-04041-4

REVIEW

# The role of stereotactic radiosurgery in the management of petroclival meningioma: a systematic review

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Received: 4 April 2022 / Accepted: 18 May 2022 / Published online: 18 June 2022


## Abstract

Purpose:Petroclival meningioma (PM) is a challenging neuro oncology case and stereotactic radiosurgery (SRS) is proposed as one treatment option. This systematic review aimed to examine the role of SRS in treating PM cases. Methods: We constructed a systematic review using the PRISMA guidelines using peer-reviewed English literature until 16 February 2022 from EuroPMC and PubMed. We used the terms petroclival meningioma, clival meningioma, apex petrous meningioma, spheno petroclival meningioma, stereotactic radiosurgery, radiosurgery, CyberKnife, Gamma Knife, linear accelerator, LINAC, and radiotherapy. Results: 10 out of 266 studies were chosen for this systematic review, two of which are case reports. The study comprised 719 patients, 73.7% of whom were female (n = 530) and had a median age of 56.99 years (18–90 years). At the time of diagnosis, the median tumor volume was 6.07 $cm^3$ (0.13–64.9 $cm^3$). The tumors were frequently located near the petroclival junction (83.6%, n = 598). Following SRS, the median follow-up was 64.52 months (3–252 months). 46.5% of 719 PMs exhibited a decrease in tumor size. 46% and 7.5% showed no change and increase in tumor volume, respectively. At the last radiographic follow-up (7–21.2 years), tumor control with a median of 98.8% (85–100%). Complications occurred in 6% of patients, with hydrocephalus (2.2%) as the prevalent complication. The use of SRS as a primary treatment for petroclival cases was not associated with increased complication rate RR 0.62 (95% CI [0.11, 3.59], p = 0.59) but statistically correlated with clinical failure clinical failure RR 0.56 (95% CI [0.32, 0.98], p = 0.04). Conclusions: We found a low number of complications following SRS intervention and has been effectively controlling tumor progression.

**Keywords** Petroclival meningioma · Stereotactic radiosurgery · Management

## Abbreviations

| | |
|---|---|
| PM | Petroclival meningioma |
| SRS | Stereotactic radiosurgery |
| PRISMA | Preferred Reporting Items for Systematic Reviews and Meta-analyses |
| JBI | Joanna Briggs Institute's |
| NOS | Newcastle–Ottawa Scale |
| CNS | Central nervous system |
| M | Male |
| F | Female |
| Gy | Gray |
| VP | Ventriculoperitoneal |
| CN | Cranial nerve |
| nr | Not reported |
| NA | Not applicable |

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## Introduction

Although meningioma is the most prevalent among other benign central nervous system tumors (CNS), the incidence of PM is rare, accounting for around 2% of all types of meningioma [1]. PM is known to be surgically dangerous as they involve the brain stem, cranial nerves, and vital vascular structures [2]. Attempts at extirpation were formerly associated with a mortality rate of greater than 50%, leading many surgeons to believe that these tumors were hard to treat [2].

Because petroclival meningiomas are in such a relatively inaccessible location, various surgical techniques for their removal have been explored, which include retrosigmoid approach, Kawase's approach, petrosectomy options, and several other surgical approaches [3]. Unfortunately,

surgically removing PM is associated with a considerable risk of neurological morbidity [4].

Unresectable tumors and recurring meningiomas can also be treated with radiation. It is suggested for benign meningioma and malignant tumors after surgical intervention. Several radiation technologies, including SRS, intensity-modulated radiation therapy (IMRT), fractionated stereotactic radiotherapy (FSRT), and proton-beam therapy (PBT), have shown to be effective in treating benign cranial tumors like pituitary adenomas, craniopharyngiomas, and meningiomas [5, 6]. In a retrospective study conducted in 2014 with a total sample of 213 patients showed that there was no significant difference in terms of clinical and radiological response between SRS, hypofractionated stereotactic radiation treatment (hFSRT), and FSRT in the treatment of meningioma of the skull base [7]. However, volume and tumor topology must be taken into account while selecting a procedure. In contrast to traditional fractional radiotherapy, hFSRT is a precise approach that permits a high dose per fraction to be provided in a few clinical visit sessions while reducing the margin around the tumor and the surrounding tissue [8]. It is an excellent method for treating small lesions with greater radiobiologically effective doses in order to increase local control [7, 8].

SRS has appeared a valuable therapeutic alternative for selected patients and a primary therapy technique in the following microsurgery [9]. Due to the lack of published literature, the use of SRS as the treatment of petroclival meningioma remained undetermined. Current use of SRS is as adjuvant or treatment for small PM lesion [10]. Because of their proximity to the brainstem, cranial nerves, and vascular structures and their propensity to cause future development of hydrocephalus, petroclival meningiomas present particular complications in radiosurgical planning [9, 11–19]. In this systematic review, we aimed to determine the safety and efficacy of SRS for patients with petroclival meningioma.

## Materials and methods

The protocol of this systematic review was registered in PROSPERO (CRD42021276071) and structured following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [20]. Included studies were selected if they fulfilled the following criteria:

- Complies with the PICO framework (P: petroclival meningioma, I: stereotactic radiosurgery, C: fractionated radiotherapy, O: safety and efficacy);
- Cohort, cross-sectional and randomized or nonrandomized clinical trial studies; and
- Studies that report the outcome of interest.

The authors excluded other studies with non-human or cadaveric and studies that were not original research articles (review articles, letter to editor, or correspondence) and non-English language. We also excluded any grey and white literature due to lacking credibility.

We conducted a systematic search on two unique electronic databases, PubMed, and Europe PMC, with the following search queries: petroclival meningioma, clival meningioma, apex petrous meningioma, spheno petroclival meningioma, stereotactic radiosurgery, radiosurgery, CyberKnife, Gamma Knife, linear accelerator, LINAC, and radiotherapy. The authors conducted the literature search from 13 February 2022 until 16 February 2022. Our search strategy details are listed in Table 1. Initial screening of titles and abstracts was also done by the list of references of eligible studies. Petroclival meningioma in the current study includes meningiomas that develop from the dura medial to cranial nerves located between the petrous apex and the upper clivus [21]. This includes petroclival, clival, and spheno petroclival. The primary outcome of this study is the safety and efficacy of stereotactic radiosurgery for petroclival meningioma patients.

Two independent authors (J.H and Y.Y) carried out literature searches. Upon conclusion of electronic queries, we eliminated duplicate papers. The titles and abstracts of the remaining publications were then screened and examined with the inclusion, as mentioned earlier, and exclusion criteria. Any unresolved discrepancies in determining which studies were eligible, we sought for expert consultation (J.J), and the authors decided according to his expertise and consensus. The primary and secondary outcome of current study was clinical failure and overall complications rate, respectively.

The studies that were deemed as suitable included in this systematic review, and each entered studies' quality was critically appraised using the Newcastle Ottawa Scale (NOS) for cohort studies or the Joanna Briggs Institute's (JBI) essential evaluation checklist for case reports as appropriate. In terms of data extraction, the authors collected demographic data, follow-up duration, previous treatments, parameters of radiosurgery, initial presentation tumor volume, tumor control, tumor progression, and complications. All extracted data were assessed using pooled descriptive tests.

Review Manager 5.4 (Cochrane Collaboration) was used to conduct the meta-analysis. To calculate risk ratios (RRs), we utilized the Mantel–Haenszel algorithm for dichotomous variables, which is provided along with their 95% confidence intervals (CIs). Regardless of heterogeneity, a random-effects model was utilized to calculate the results. In this investigation, all p-values were two-tailed, and statistical significance was set to 0.05. To assess the risk of publication bias, we applied an inverted funnel-plot analysis.

**Table 1** Keywords used for extracting data from the electronic archives

| Electronic archives | Keywords | Total study retrieved |
|---|---|---|
| PubMed | ((“petroclival”[All Fields] AND (“meningioma”[MeSH Terms] OR “meningioma”[All Fields] OR “meningiomas”[All Fields])) OR (“clival”[All Fields] AND (“meningioma”[MeSH Terms] OR “meningioma”[All Fields] OR “meningiomas”[All Fields])) OR ((“appl phys express”[Journal] OR “apex”[Journal] OR “apex”[All Fields]) AND “petrous”[All Fields] AND (“meningioma”[MeSH Terms] OR “meningioma”[All Fields] OR “meningiomas”[All Fields])) OR (“spheno”[All Fields] AND “petroclival”[All Fields] AND (“meningioma”[MeSH Terms] OR “meningioma”[All Fields] OR “meningiomas”[All Fields]))) AND (“radiosurgery”[MeSH Terms] OR “radiosurgery”[All Fields] OR (“stereotactic”[All Fields] AND “radiosurgery”[All Fields]) OR “stereotactic radiosurgery”[All Fields] OR (“radiosurgeries”[All Fields] OR “radiosurgery”[MeSH Terms] OR “radiosurgery”[All Fields]) OR “CyberKnife”[All Fields] OR (“radiosurgery”[MeSH Terms] OR “radiosurgery”[All Fields] OR (“gamma”[All Fields] AND “knife”[All Fields]) OR “gamma knife”[All Fields]) OR (“particle accelerators”[MeSH Terms] OR (“particle”[All Fields] AND “accelerators”[All Fields]) OR “particle accelerators”[All Fields] OR (“linear”[All Fields] AND “accelerator”[All Fields]) OR “linear accelerator”[All Fields]) OR (“linac s”[All Fields] OR “linacs”[All Fields] OR “particle accelerators”[MeSH Terms] OR (“particle”[All Fields] AND “accelerators”[All Fields]) OR “particle accelerators”[All Fields] OR “linac”[All Fields]) OR (“radiotherapy”[MeSH Terms] OR “radiotherapy”[All Fields] OR “radiotherapies”[All Fields] OR “radiotherapy”[MeSH Subheading] OR “radiotherapy s”[All Fields])) | 125 |
| EuroPMC | petroclival meningioma OR clival meningioma OR apex petrous meningioma OR spheno petroclival meningioma AND stereotactic radiosurgery OR radiosurgery OR CyberKnife OR Gamma Knife OR linear accelerator OR LINAC OR radiotherapy | 83 |

## Results

The searches on the databases yielded 208 studies. Through the elimination of duplicate articles, a total of 161 studies remained to be assessed. We eliminated another 120 studies after screening through the titles and abstract while matching those articles with inclusion and exclusion criteria (Fig. 1). Further evaluation for articles eligibility on 41 full-text articles was carried out. A total of 31 articles were then excluded, 4 had no full-text availability, 21 were not considered SRS, 4 were not petroclival meningioma, and 2 were not English. As a result, ten studies were included in this systematic review; eight studies were retrospective studies and two case reports studies [9, 11–19]. All literature stated they used the same treatment modality, which is gamma knife radiosurgery (GKRS) with specified dose presented in Table 2.

The study comprised 719 patients, 73.7% of whom were female (n = 530) and had a median age of 56.99 years (18–90 years). The most common presenting symptom was CN V deficits (n = 217). It is noteworthy that symptoms other than CN deficits were presented in a limited fraction of patients and the authors assumed to be absent when symptoms not mentioned. At the time of diagnosis, the median tumor volume was 6.07 $cm^3$ (0.13–64.9 $cm^3$). The tumors were frequently located near the petroclival junction (83.6%, n = 598). Following SRS, the median follow-up was 64.52 months (3–252 months). 46.5% of 719 PMs exhibited a decrease in tumor size. Of note, 4 patients and 3 patients from the total cohort were diagnosed with WHO Grade II and III meningiomas, respectively. 46% and 7.5% showed no change and increase in tumor volume, respectively. At the last radiographic follow-up (7–21.2 years), tumor control with a median of 98.8% (85–100%).

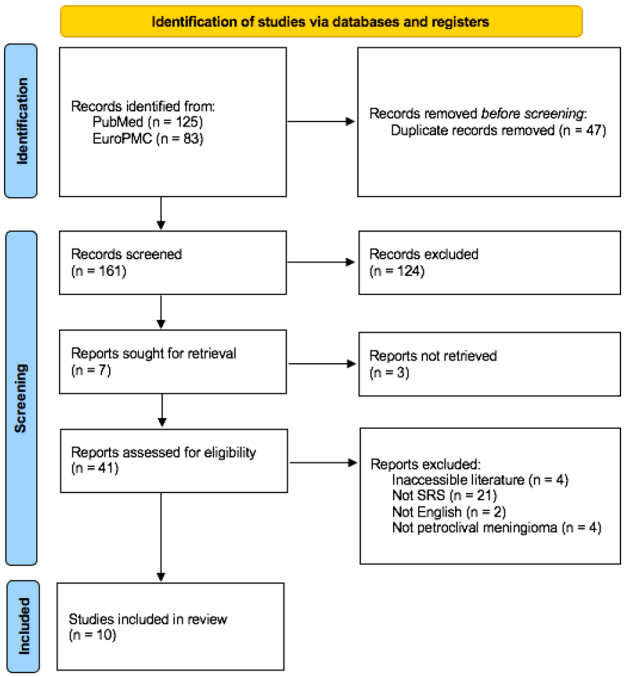


**Fig. 1** PRISMA flow diagram

There are a total of 353 individuals received SRS as a primary treatment, whereas 378 received SRS as a secondary outcome following microsurgery (n = 261), fractioned radiotherapy (n = 5), and 73 are at recurrence treatment of SRS. The remaining individuals treatment data was not described.

The most prevalent complication documented in this study was hydrocephalus, accounting for 16 patients out of 719 patients data available. The second and third most common complications following SRS for PM patients were cystic formation (n = 7) and tumor regrowth (n = 5). Brainstem dysfunction and vestibulocochlear nerve deficits were reported in 3 patients each. All other complications, such as intracerebral hemorrhage, asymptomatic dural lacerations, and new imaging signs, were reported in 1 patient each. Detailed patient demographic characteristics were summarized in Table 3.

Following a long follow-up time, our pooled data showed that 29 patients required additional treatment following SRS intervention. VP shunts were performed in 15 patients, additional surgery was conducted in 13 patients, and one patient was reported to undergo additional radiotherapy.

## Meta-analyses

The use of SRS as a primary treatment for petroclival cases was not associated with increased complication rate RR 0.62 (95% CI [0.11, 3.59], p = 0.59) but statistically correlated with clinical failure clinical failure RR 0.56 (95% CI [0.32, 0.98], p = 0.04). The meta-analyses were attached below (Figs. 2, 3).

## Discussion

PMs are one of the most challenging skull base tumors to treat [4]. The difficulty of obtaining long-term tumor control while avoiding neurological morbidity and mortality is hard underlined by their diverse development patterns and the nearby neurovascular structures [3, 13]. The standard of care for deep-seated skull base tumors like PMs has evolved from aggressive gross complete surgical excision to a more moderate approach [3, 4, 22, 23]. Various surgical techniques, on the other hand, are frequently accompanied with severe morbidity [24]. Henceforth, in this study, we aimed to determine the safety and efficacy of SRS for patients suffering PM.

### Surgical resection

Although complete surgical resection of petroclival meningiomas may be curative, the morbidity and mortality associated with this procedure can be very high [10]. According to one study, 44% of patients with petroclival meningioma who underwent surgical excision developed new postoperative cranial neuropathies, with 14% developing permanent cranial nerve palsies. Hydrocephalus necessitating cerebrospinal fluid (CSF) diversion (16%), CSF leak (4%), and wound dehiscence were among the other surgical problems (2%). With a median time to recurrence of 84 months, 19% of the 31 patients with at least 6 months radiologic follow-up (mean 22 months) experienced tumor progression or recurrence [10].

### Fractionated radiotherapy

Another treatment option for PMs is radiation, which is frequently used in conjunction with surgery [25]. Radiosurgery (a massive dosage of radiation directed at the tumor) and fractionated radiotherapy (several little doses of radiation provided over several weeks) are the two methods for delivering radiation. Fractionated radiotherapy exposes lower amounts of radiation over treatment sessions. In meningiomas developed within critical areas, such as PCM, fractionated radiation is more typically preferred [18].

Multiple studies have found that fractionated external beam radiation (EBRT) is comparable to SRS in terms of progression-free survival [26, 27]. Small tumors (2.5–3 cm) located away from important structures like the optic nerves have been treated with single fraction radiosurgery [27]. However, because abnormally high rates of local recurrence have been documented, it appears that this approach cannot be applied to meningiomas with volumes greater than 7.5 cc

**Table 2** Summary of findings of eligible studies

| Authors & year/NOS assessment | Total patients (M/F) | Median age (median, range, year) | Median marginal dose (Gy) | Median radiological follow-up (range, months) | SRS (primary/adjuvant) | Median tumor volume ($cm^3$) | Tumor size (decreased/stable/worsened) (N) | Tumor control % at last follow-up | Progression free survival (%) | | Tumor site (petroclival/clivus/spheno petroclival) | Complications | Additional treatments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 5-year | 10-year | | | |
| *Cohort studies* | | | | | | | | | | | | | |
| Kim 2017/7 (good) | 89 (23/66) | 50 (15–74) | 13.2 (8–17) | 63 (3–195) | 58/31 | 6.7 (0.5–46.3) | 50/34/5 | 94.4% (195 months) | 94.7 | 88.9 | 72/13/4 | Regrowth (5), cyst formation (7) | Surgical decompression (5) |
| Starke 2014/6 (good) | 229 (34/195) | 57.1 (18–89) | 15 (11–20) | 71 (6–252) | 136/118 | 7.8 (0.2–36.1) | 98/129/2 | 87% (252 months) | 93 | 84 | 229/0/0 | Hydrocephalus (7) | VP shunt (7), radiotherapy (1), surgery (8) |
| Sadik 2018/7 (good) | 53 (7/46) | 57.8 (33–90) | 13 (11–15) | 59 (12–147) | 53/0 | 4 (0.1–11.4) | 49/3/1 | 93% (84 months) | 98 | 93 | 53/0/0 | CN deficits (2) severe pain (1) | NA |
| Subach 1998/6 (moderate) | 62 (47/15) | 56 (nr) | 30 (20–50) | 35 (4–95) | 15/47 | 13.7 (0.8–56.8) | 13/41/8 | 86.7 (96 months) | NA | NA | 22/6/34 | Brainstem depression (1), asymptomatic dural laceration (1), CN deficits (5) | VP shunt (1) |
| Ha 2020/8 (good) | 64 (23/41) | 62 (27–88) | 12 (10–14) | 58.4 (6–164) | 52/0 | 13.4 (0.4–64.9) | 57/0/7 | 58.6% (164 months) | 91.1 | 69.6 | 30/0/34 | CN deficits (8), hemiparesis, cognitive dysfunction, and hydrocephalus (2) | NA |
| Roche 2003/6 (good) | 32 (5/27) | 53 (34–77) | 13 (10–15) | 48 (24–118) | 24/8 | 2.3 (0.3–6) | 13/19/0 | NA | 100 | NA | 6/7/19 | Brainstem dysfunction (3) | NA |

**Table 2** (continued)

| Authors & year/NOS assessment | Total patients (M/F) | Median age (median, range, year) | Median marginal dose (Gy) | Median radiological follow-up (range, months) | SRS (primary/adjuvant) | Median tumor volume ($cm^3$) | Tumor size (decreased/stable/worsened) (N) | Tumor control % at last follow-up | Progression free survival (%) | | Tumor site (petroclival/clivus/sphenopetroclival) | Complications | Additional treatments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 5-year | 10-year | | | |
| Flannery 2010/6 (good) | 168 (44/124) | 57 (nr) | 13 (9–18) | 64 (3–204) | 95/71 | 6.1 (0.3–32.5) | 44/98/26 90% (254 months) | | 91 | 86 | 166/0/0/ | CN deficits (3), cerebellar symptoms (2), new imaging signs (4), hydrocephalus (7), intracerebral hemorrhage (1) | VP shunt (7) |
| Bir 2016/7 (good) | 6 (3/3) | 47 (21–66) | NA | 149 (62–236) | 0/6 | 1.4 (0.8–2) | 0/1/5 NA | | 100 | NA | 6/0/0 | NA | NA |
| *Case series* | | | | | | | | | | | | | |
| Kano 2011/7 (good) | 12 (2/10) | 54 (37–68) | 13 (11–16) | 68 (25–180) | 12/0 | 3.8 (1–15.9) | 8/4/0 NA | | NA | NA | 12/0/0 | NA | NA |
| Mureb 2020/7 (good) | 4 (1/3) | 76 (59–90) | 12.3 (12–12.5) | 29.8 (12–49) | 4/0 | 1.5 (1.1–2.5) | 2/2/0 NA | | NA | NA | 4/0/0 | NA | NA |

*M* male; *F* female; *Gy* gray; *VP* ventriculoperitoneal; *CN* cranial nerve; *nr* not reported; *NA* not applicable

**Table 3** Detailed patient demographics of included studies

| Variable | Number of available patients data | Frequency (%) |
|---|---|---|
| *Previous treatment before SRS* | | |
| Surgical | 609 | 261 (42.9) |
| Stereotactic radiosurgery | 189 | 73 (38.6) |
| Radiotherapy | 316 | 5 (1.6) |
| None | 719 | 376 (52.3) |
| *Initial presentation* | | |
| CN I | 719 | 2 (0.3) |
| CN II | 719 | 9 (1.3) |
| CN III/IV/VI | 719 | 216 (30) |
| CN V | 719 | 217 (30.2) |
| CN VII | 719 | 174 (24.2) |
| CN VIII | 719 | 169 (23.5) |
| CN IX/X/XI/XII | 719 | 60 (8.3) |
| Headache | 426 | 85 (20) |
| Dizziness | 420 | 72 (17.1) |
| Cerebellar symptoms | 719 | 92 (12.8) |
| Weakness | 254 | 13 (5.1) |
| Change body sensation | 254 | 1 (0.4) |
| Balance problems | 166 | 49 (29.5) |
| Hearing loss/tinnitus | 172 | 48 (28) |
| *Tumor site* | | |
| Petroclival | 719 | 598 (83.6) |
| Clival | 719 | 26 (3.6) |
| Sphenopetroclival | 719 | 71 (10.1) |
| Petrous apex | 719 | 19 (2.7) |
| *Tumor extension* | | |
| Cerebellopontine angle | 391 | 11 |
| Cavernous sinus | 391 | 33 |
| Meckel's cave | 391 | 20 |
| Tentorium | 391 | 5 |
| Vascular structure | 391 | 2 |
| *Complications* | | |
| Cystic formation | 719 | 7 (1) |
| Hydrocephalus | 719 | 16 (2.2) |
| Brainstem compression | 719 | 1 (0.1) |
| Brainstem dysfunction | 719 | 3 (0.4) |
| Asymptomatic dural laceration | 719 | 1 (0.1) |
| Abducens nerve palsies | 719 | 1 (0.1) |
| Vestibulocochlear nerve palsies | 719 | 3 (0.4) |
| Trigeminal nerve palsies | 719 | 1 (0.1) |
| Hemiparesis | 719 | 1 (0.1) |
| Cognitive dysfunction | 719 | 1 (0.1) |
| Cerebellar symptoms | 719 | 1 (0.1) |
| Intracerebral hemorrhage | 719 | 1 (0.1) |
| New radiographic signs | 719 | 1 (0.1) |

[27]. Han et al. examined SRS and FSRT in the treatment of skull-base meningioma, noting that clinical response was seen in 89%, 80%, and 91% (p = 0.16) of patients in the SRS, hFSRT, and FSRT groups, respectively [7]. A study led by Metellus found that 58% of patients managed with Gamma Knife radiosurgery for cavernous sinus meningiomas showed a clinical improvement [28].

A former study of 22 studies of cavernous sinus meningiomas found that lesions exceeding 2 cm could continue to increase by 10% in size each year, with a risk of becoming symptomatic in 42% of lesions less than 2 cm [29]. Furthermore, there is no well-established consensus on how to treat asymptomatic meningiomas of the skull base, such as the cavernous sinus meningioma [30, 31]. One of our study limitation is that there are limited data on comparison between SRS and fractionated radiotherapy in the literature. Thus, we were not able to synthesize the comparison within modalities.

## Safety

In terms of the usage of SRS in PM cases, we detected a 2.5% rate of neurological impairment throughout a reasonably lengthy follow-up period of a mean 64.5 (3–252) months. The most prevalent baseline deficiency was CN V, but the most common post-SRS deficit was also new or worsening CN V function. In addition, hydrocephalus as one of the most prevalent complications was observed.

The report of hydrocephalus as one of the postoperative complications following SRS is inadequately documented in the case of PMs [32–34]. A review of the literature on postoperative hydrocephalus after using SRS in managing cerebellopontine angle tumor described a 4–6% complication rate [35]. According to Noren et al., the tumor caused considerably more cases of hydrocephalus than the treatment [35]. As a result, they discovered that a shunt was implanted in 9.2% of GKRS patients, and in 5.5% of which was before radiosurgery. Pirouzmand et al. investigated the role of radiosurgery in the development of hydrocephalus, but found no statistically significant result [36]. Although some authors hypothesized that symptomatic hydrocephalus could be explained by a release of protein and cellular debris as a result of radiation-induced necrosis, this mechanism was quite contentious [37].

A more than 10 cc tumor volume was the only independent predictor of shorter survival in a single-center GKRS investigation of 137 patients with intracranial meningiomas [38]. In comparison to our study, we could not analyze at what size PM can shorten the survival of one individual; this is one of our limitations, and future research may be desirable in addressing the current gap. One elegant study conducted by Roche et al. analysing GKRS outcomes for 32 patients with petroclival meningiomas, a mean follow-up of

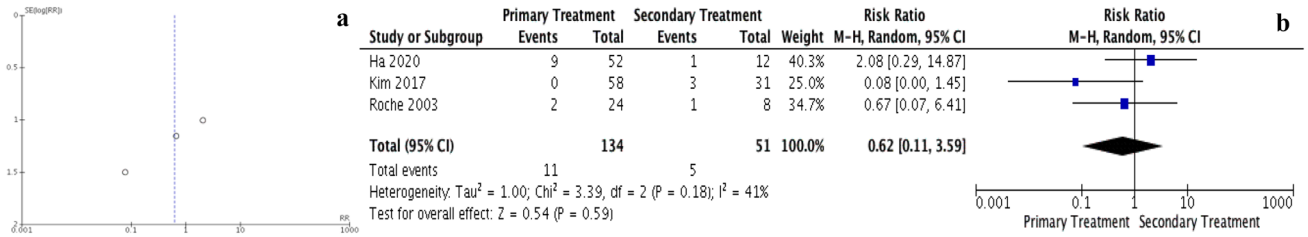


**Fig. 2** Showing meta-analysis of complication rate in form of **a** funnel plot and **b** forest plot

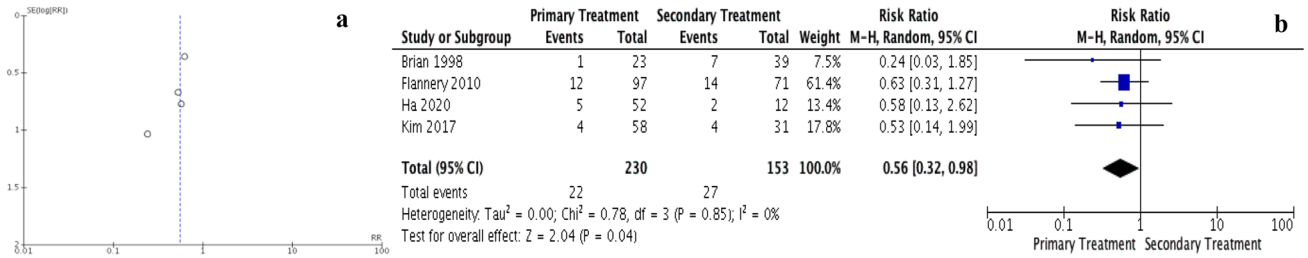


**Fig. 3** Showing meta-analysis of clinical failure in form of **a** funnel plot and **b** forest plot

53 months, showed that the tumor control rate was 100%, and the percentage of positive outcomes was 94% [16]. After radiosurgery, two patients experienced stroke symptoms associated with pontine infarcts, according to the authors. Another study was conducted by Flannery et al. in 2010 compromising of 168 patients with a median follow-up of 72 months using GKRS [12]. The report conducted by Flannery et al. is also included in the current systematic review. At 5 and 10 years, the progression-free survival rates were 91 and 86%, respectively, which is comparable to the tumor control rates reported in this study. Tumor sizes of at least 8 cc and male gender were significant predictors of tumor growth, with a 15% probability of neurological impairment [12].

## Efficacy

The current investigation is the first study in critically and systematically reviewing published literature in determining the safety and efficacy of SRS as one of the treatments for PM. GKRS has a an overall tumor control rate at mean of 98.8% (85–100%), after a mean follow up of There was also a 46.5% of 719 PCMs reduction in the average tumor volume. Previous literature found the following factors to be predictors of tumor progression, such as prolonged time from symptom onset, prior radiation therapy, increased tumor volume, and lower maximal dose [39]. Meningiomas that have been irradiated have previously been found to be more radioresistant to radiosurgery [39]. It is uncertain whether particular meningiomas' subtypes are more radioresistant or if previous ionizing radiation lessens sensitivity to more ionizing radiation [40]. Alternatively, this conclusion could be because previously irradiated meningiomas were chosen and given a lower radiosurgical dose [40].

Larger tumor volumes make it more difficult to provide the best-prescribed dose to the tumor margin while also staying within the tolerance of nearby structures, including the brainstem and neurovascular systems [41]. Lowering the marginal amount reduces the chances of successful tumor control. However, the neighboring brainstem and cranial nerves must alter the top limit of the tumor border radiosurgical dose. An ideal margin dosage to a WHO grade I petroclival meningioma would be roughly 15 Gy, or a 50% isodose line is used (ranging from 8 to 50 Gy in this study) [39]. In previous investigations, similar dose regimens have also been demonstrated to offer an effective and safe outcome after one radiosurgery session [39]. Although examining previously treated patients may provide some guidance for GKRS treatment planning, each patient's patient and tumor features must be assessed individually to establish the best therapy strategy [15]. Increasing the dose seemingly improves the likelihood of tumor control, but it must be balanced against the danger of radiation-induced harm that comes with increasing the radiosurgical margin dose [42].

## Study limitations and future directions

Studies on PCMs are confined, as highlighted in this systematic review; hence, the authors undertook the only descriptive analysis. A quantitative pooled analysis or other types

of the meta-analysis was also not achievable in this review due to the heterogeneity of the included papers. Because we limited this search to English-language publications, missing data from foreign-language publications is presumable. Another limitation is that we were unable to provide a clear description for the study 5- and 10-year outcomes since most of the literature assumes that late failures will occur at the same rate as early failures. For diseases with a late failure propensity, such as meningioma, actuarial data does not work well.

## Conclusions

This systematic review synthesized evidence from ten studies that looked into the use of SRS in treating PM cases. We found a low number of complications following SRS and have been effectively controlling tumor progression in PM cases. The recent surge in SRS utilization and development provides a chance to develop further and evaluate the long-term safety and efficacy of the technology. However, we were still facing several limitations; In which case, further study may elucidate the safety and efficacy of SRS as a feasible option in treating PM cases.

**Acknowledgements** None.

**Author contributions** All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by JHW, YEA, and JJ. The first draft of the manuscript was written by JHW and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

**Funding** This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

**Data availability** The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

## Declarations

**Competing interests** The authors declare no competing interests.

**Ethical approval** Not applicable.

**Consent to participate** Not applicable.

**Consent to publish** Not applicable.

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